RFI TECHNOTE 029

Longitudinal Schottky Pickup for the Recycler

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Abstract: *A longitudinal schottky pickup has been built for the recycler. It is to be used as a very sensitive beam current monitor, and as a tool to measure synchrotron frequencies. The pickup is based on a pickup designed for the anti-proton source accumulator, and has a resonant frequency of 79.203 MHz.*

Logitudinal Schottky Pickup Basics

In a circular particle accelerator/storage ring, a single particle with charge e and revolution frequency f_0 can be represented as

$$i(t) = ef_0 \sum_{n=-\infty}^{\infty} \exp(j2n\pi f_0 t) = ef_0 + 2ef_0 \sum_{n=1}^{\infty} \cos(2n\pi f_0 t)$$

as observed at a point on the accelerator. In frequency space the above are lines at f_0 and its harmonics. If we sum the above equation over N particles, each with slightly different revolution frequencies, then the lines become bands, and the r.m.s. current per band is proportional to the square root of the number of particles:

$$i_{rms} = 2ef_0\sqrt{\frac{N}{2}}\ ,$$

The total power in a Schottky band remains constant, independent of n, the harmonic number, but the power spectral density is proportional to the number of particles in the beam divided by the frequency spread of the beam:

$$\text{P.S.D.} \propto \frac{< i^2 >}{\Delta f}\ ,$$

where Δf is related to the momentum dispersion function, η, of the lattice, and $\frac{\Delta p}{p}$, the momentum spread of the beam, as follows:

$$\Delta f = nf_0\eta\frac{\Delta p}{p}\ ,$$

As n increases, the power spectral density decreases, resulting in worse signal-to-noise ratios. Furthermore, the separation between two adjacent bands is roughly (Fig. 1)

$$f_0 - n\Delta f_0 ,$$

for large n. For sufficiently large n, the bands start overlapping each other. Let f_n denote the nth harmonic of the revolution frequency chosen for the pickup resonance, $f_n = nf_0$. In order to avoid overlapping bands, we need

$$f_0 - n\Delta f_0 > 0 ,$$

or equivalently

$$\frac{f_0^2}{\Delta f_0} > f_n .$$

The upper frequency limit below overlapping for the recycler detector is about 1 GHz.

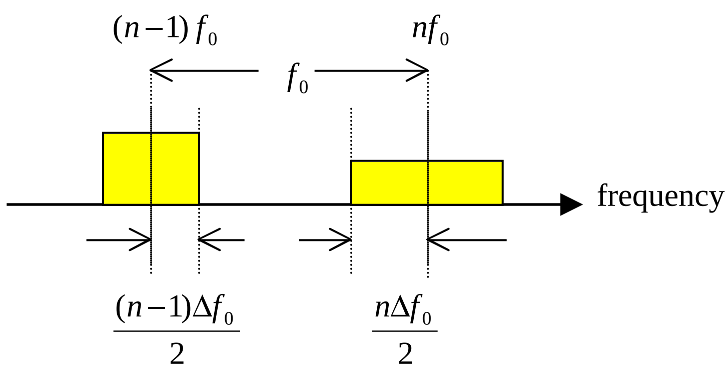

Fig. 1 Schottky bands separation $\cup f_0 - n\Delta f_0$ for large n.

In a bunched beam, the particles will execute synchrotron oscillations with respect to the synchronous particles, and the arrival time of particles at the detector is modulated by an additional term

$$\tau \sin(\Omega t + \varphi),$$

Where τ, Ω and φ are the amplitude, frequency and phase of the particles with respect to the synchronous particles. Then the longitudinal signal becomes

$$i(t) = ef_0 + 2ef_0 \sum_{n=1}^{\times} \sum_{k=-\times}^{\times} j_k (2\pi n f_0 \tau) \cos[(2\pi n f_0 + k\Omega)t + k\varphi],$$

where j_k is the Bessel function of order k. Displayed in frequency, the revolution lines consist of a central line (j_0 term) and satellites spaced at Ω and amplitudes determined by the Bessel coefficients.

Pickup Design

The longitudinal schottky can be viewed as a quarter wave open-circuit transmission line stub. The beam pipe is the center conductor of a coaxial transmission line, and an outer shell on the outside of the beam pipe acts as the outer conductor of the coaxial transmission line. To simulate the effect of an open-circuited transmission line, a ceramic gap is placed in the beam pipe. A schematic of the pickup is shown in fig.2. The quarter wave structure has a resonant frequency of 79.203 MHz (n = 882). A type N connector is used to extract the signal when the structure is resonating. A braided wire is soldered from the center pin of the type N connector and is connected to the center beam pipe using a metal "worm" clamp. The resonant frequency of the structure is tuned by adjusting the position of outer shell. To match the impedance of the resonant structure to 50 Ohms, the position of the metal worm clamp is adjusted. With these two adjustments, the impedance, at a given resonant frequency, can be matched very well to 50 Ohms. The Fermilab assembly drawing for the schottky pickup is 0231.000 MD-322188.

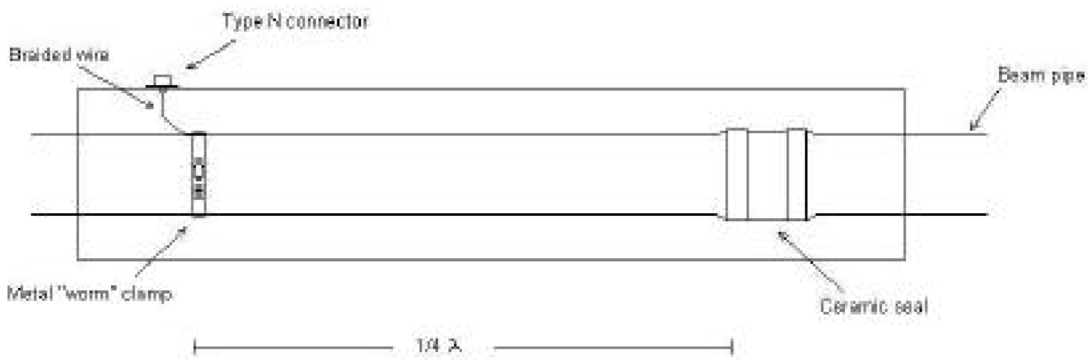

Fig. 2. Longitudinal schottky pickup

Pickup measurement

The schottky pickup has a resonant frequency of 79.203 MHz. A 1-port s11 calibration was done to a network analyzer to look at the impedance seen looking into the schottky pickup. The impedance is to matched to 50 Ohms at the resonant frequency. A plot of the reflection coefficient seen looking into the schottky pickup is shown in fig.3. The impedance is shown on a smith chart plot in fig.4.

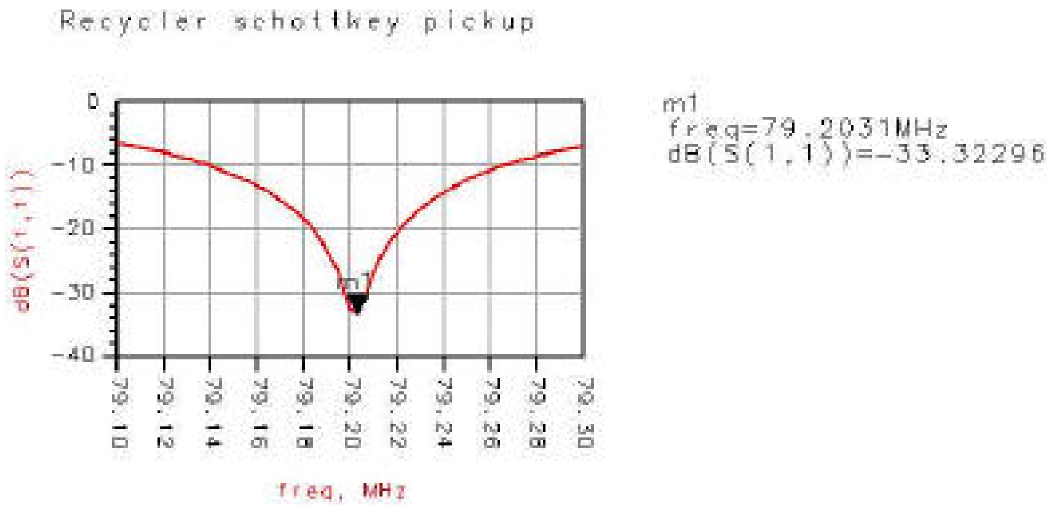

Fig.3. Reflection coefficient seen looking into the schottky pickup

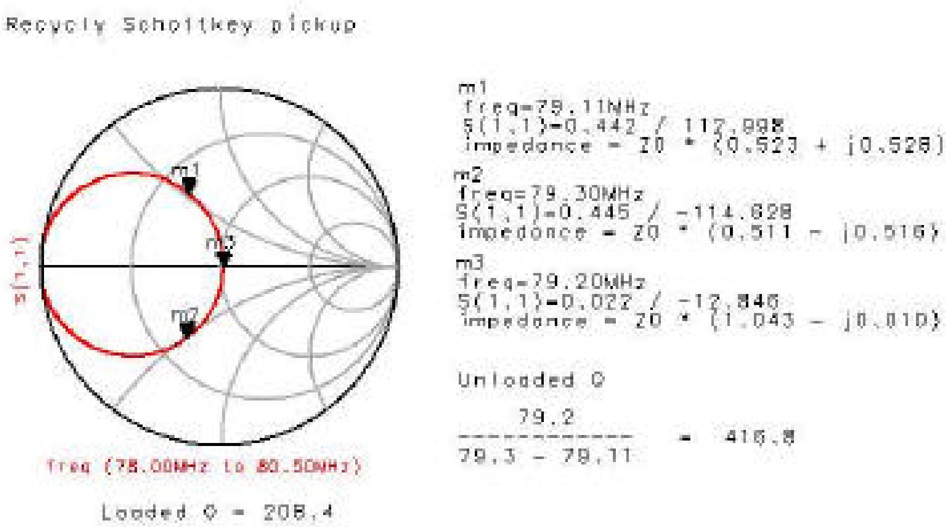

Fig.4. Impedance plotted on a smith chart

Markers are placed at points were the real impedance is equal to the imaginary impedance. These points are used to determine the Q of the pickup. The Q is derived using the following equation.

$$Q(\text{unloaded}) = \frac{\text{resonant frequency}}{F2 - F1}$$

F1 = first frequency point where the real impedance is equal to the imaginary impedance

F2 = second frequency point where the real impedance is equal to the imaginary impedance

Using the smith chart shown in fig.4, F1 and F2 are determined, and the unloaded Q and loaded Q is calculated below. The loaded Q for a well matched circuit is about _ the unloaded Q.

Q(unloaded) = 416.8

Q(loaded) = 208.4

Pickup installation

The schottky pickup is in the MI 60 section. A low noise amplifier is used to amplify the signal at the output of the schottky pickup. The amplifier used is a M/A Com A75-3 10-500 MHz low noise amplifier. It runs off a 15 volt power supply, has about 18 dB of gain, and has noise figure of 1.7 dB. Photographs of the installed pickup are shown in the figures below.

Fig.5. Logitudinal Schottky

Fig.6. Low noise Amplifier